

Hyperspectral Remote Sensing of the Coastal Ocean: Adaptive Sampling and Forecasting of Near-Shore *In Situ* Optical Properties

W. Paul Bissett
Florida Environmental Research Institute
4807 Bayshore Blvd.
Suite 101
Tampa, FL 33611
phone: (813) 837-3374 x102 fax: (813) 902-9758 email: pbissett@flenvironmental.org

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LONG-TERM GOALS

Water clarity is a key parameter of coastal ecology, as well as being important to some near-shore Naval operations. The clarity of the water column depends upon the depth-dependent distribution of the inherent optical properties and the geometric structure of the light field (an apparent optical property). Our long-term goal is to develop the remote sensing techniques, data analysis, and modeling capabilities to nowcast and forecast the 3-dimensional Inherent and Apparent Optical Properties [IOPs and AOPs] of the near-shore coastal environment.

OBJECTIVES

- 1) To develop and deploy optical systems in the coastal ocean to ground-truth remote sensing imagery.
- 2) Reformulate 1-dimensional Ecological Simulation 1.0 into 3-dimensional simulation of the coastal IOPs and AOPs, and couple this new code with the Regional Ocean Modeling System [ROMS] being developed at Rutgers University.
- 3) Develop the techniques to incorporate IOPs measured from in situ, and suggested from inversion of remote sensing data, into a 3-dimensional nowcast/forecast model of the Long-term Ecological Observatory at 15 meters [LEO-15] off the coast of New Jersey.

APPROACH

Optical properties are well suited for rapid environmental assessment, as the instrumentation to measure absorption, attenuation, and water-leaving radiance are more engineered than those to determine organism biomass or quantity. For the coastal ocean resource manager, optics could become the proxy by which the ecosystem is quantitatively described. Thus, forecasting the optical properties of the coastal zone would be a boon to environmental resource managers, as well as those Naval operations that depend upon water clarity. It would demonstrate the coupling of predictive physical and ecological models, which rely on fundamental quantitative understanding of the processes operating in the marine environment. It would also facilitate the efficient allocation of scientific resources during critical times of environmental study, i.e., adaptive sampling.

The breath of area, as well as the rapid change of the water conditions in the coastal ocean makes any sampling, optical or otherwise, very time consuming and difficult. However, the focus on optics allows us to explore remote sensing techniques that can rapidly sample large areas, either by aircraft or satellite sensors. Optical remote sensing techniques have generally relied on empirical methods to invert the water-leaving radiance signal to relative measures of optical constituents, e.g. chlorophyll *a* (Gordon et al., 1983), or apparent optical properties, e.g., diffuse attenuation coefficients (Austin and Petzold, 1981). These inversion techniques assume a homogenous optical layer and were developed mainly for open ocean conditions. Thus, they have difficulties in more turbid coastal waters. Newer techniques have been developed for coastal waters that optimize the water-leaving radiance signal over many different wavelengths (Gould and Arnone, 1998), but these techniques require in situ measurements during the collection of the remote sensing data.

We hypothesize that predictions of in situ IOPs could be used in these algorithms as a means of constraining their optimization equations. In addition, the remote sensing data would provide an ideal initialization and validation data stream with which to constrain both the physical and ecological simulations. Thus, it is clear that the future development of both optical remote sensing techniques and predictive models of IOPs would benefit by being coupled together. This project is part of a larger effort to facilitate this development. It is a collaborative effort with many of the PIs in ONR's Hyperspectral Coastal Ocean Dynamics Experiment [HyCODE] and, in particular, is funded as part of a larger project with O. Schofield (Rutgers University, Award N00014-99-1-0196).

WORK COMPLETED

We continued to develop the H-TSRB data stream as a means to validate our hyperspectral input data needed for the forecasting of the inherent optical properties. This included using H-TSRB data from the 2001 HyCODE experiment and comparing it to the RADTRAN simulation data (Gregg and Carder, 1990) for the same time period. This RADTRAN data is used as input for the EcoSim/ROMS simulation.

This year's major focus was to complete the re-coding of EcoSim 2.0 so that it would be compatible with the ROMS physical circulation code (<http://marine.rutgers.edu/po/models/roms.html>). In fact, we attempted to complete the coupling of the two codes for on-line simulations prior to the HyCODE July 2001 field campaign. (On-line simulations refer to both codes running simultaneously rather than the physical output used in an off-line run of the ecological/optical forecast). This was a much more significant endeavor than the recoding of EcoSim 1.0 to handle 3-dimensional advective flow fields from the ROMS code (see last year's progress report), in that we had to significantly reduce the code space, alter the flow of the ecological code, and reduce our error checking procedures, while maintaining the integrity of the calculations, in order to run with the highly compact, parallel version of ROMS. It was felt that this coupling of in-line codes would facilitate a more rapid demonstration of the predictive capabilities of the EcoSim/ROMS optical forecast system, thus increasing the probability of achieving the overall HyCODE goals.

RESULTS

Figure 1 shows the comparison between RADTRAN and H-TSRB on July 30, 2001. There appears to be a reasonable agreement between the simulated downwelling irradiance and the measured downwelling irradiance. However, there are some differences in the blue that require some further analysis. In addition, it also appears that there are some extreme dips in the RADTRAN data that are

not seen in the H-TSRB data. These differences will probably not have much impact on the ecological simulation or the IOP prediction, however it will have a direct impact on predictions of L_w . We will continue to focus on the development of the H-TSRB data stream as a validation data source for the simulated irradiance fields, as well as a means to help atmospherically correct our aircraft's hyperspectral data (see N00014-00-01-0514).

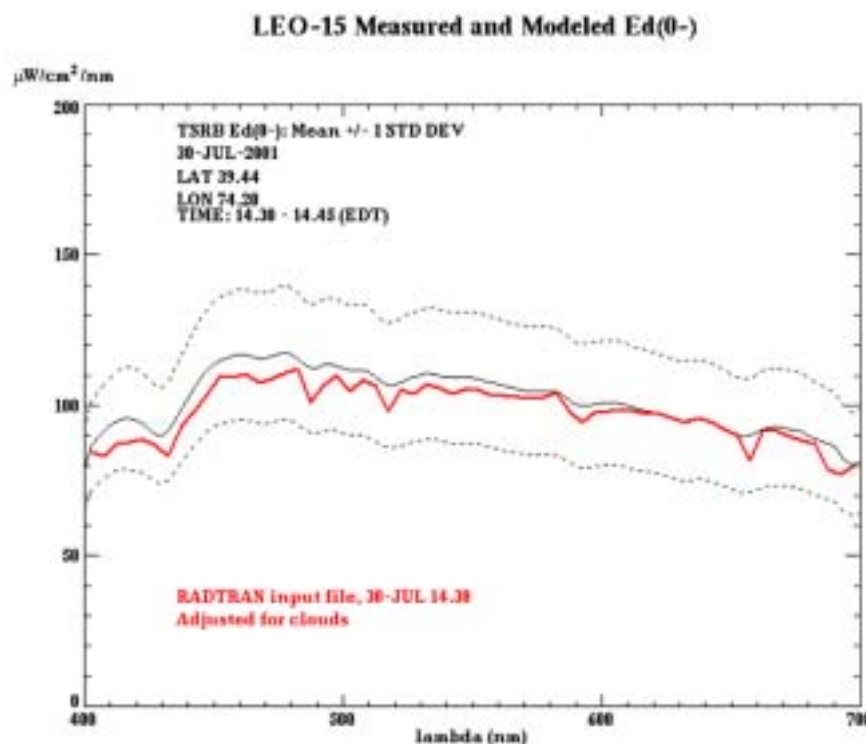


Figure 1. Modeled and Measured Downwelling Irradiance at the Sea Surface. Modeled data from RADTRAN, measured data from H-TSRB on July 30, 2001.

We completed the re-coding as well as demonstrated the parallel version of EcoSim/ROMS. Unfortunately, while the coding was completed prior to the field experiment, debugging was not. While at Rutgers Marine Field Station, we were able to complete the debugging to the coupled code, but not before the end of the experiment. Figure 1 shows the test case example of a chlorophyll *a* transect through an idealized 5 by 80 gridded basin with an upwelling favorable eastern edge and a downwelling favorable western edge. For this test case, EcoSim was run with 60 wavelength bands, 4 phytoplankton functional groups of phytoplankton, 7 phytoplankton pigments groups, 6 nutrient pools, 2 DOM pools, 2 CDOM pools, and 2 detritus pools, and included the IOP descriptions of the optical constituents.

We are now prepared to run this code with the hindcast simulations of the HyCODE field experiments from 2000 and 2001, and develop the necessary initialization and validation procedures for a nowcast/forecast optical system. In addition, the code is scalable and designed for use on the DoD HPCMP supercomputers.

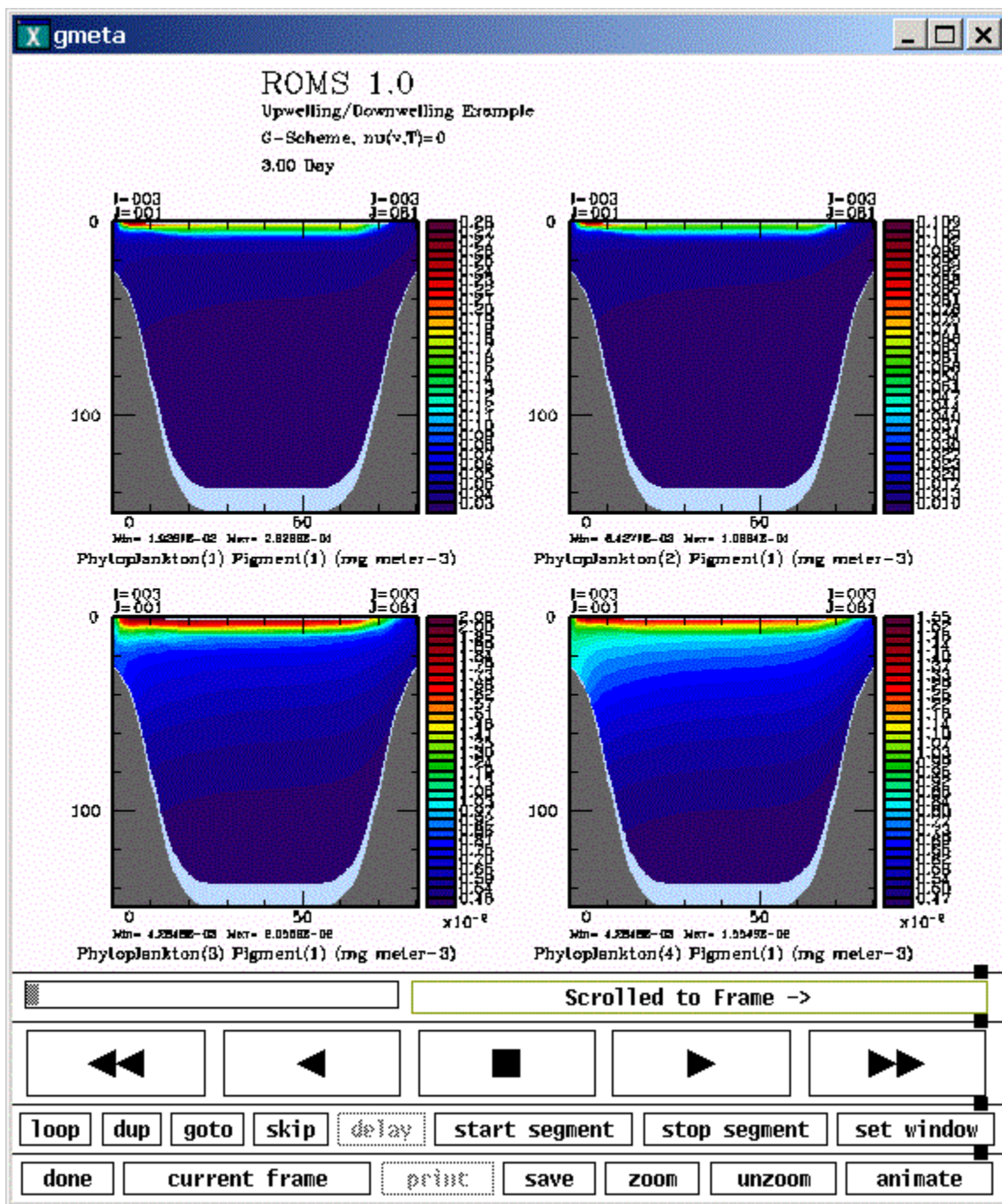


Figure 1. Example of EcoSim/ROMS output from 3-dimensional idealized basin. This simulation used idealized upwelling and downwelling favorable winds on each side of the basin. Contours are chlorophyll a for each functional group.

IMPACTS/APPLICATIONS

To forecast the clarity of the water column over both short- and long-term time horizons requires an accurate quantification of the ecological cycling of CDOM. Incorporation of a validated set of CDOM

equations into a larger three-dimensional ecological simulation will increase the veracity of the predictions of Inherent and Apparent Optical Properties [IOPs and AOPs], and help achieve the goal of forecasting optical properties as a function of the biological, chemical, and physical forcing.

RELATED PROJECTS

The list of HyCODE PI's is extensive and can be found at <http://www.opl.ucsb.edu/hycode.html>.

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